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Jacobsen, Moust

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EUROMECH 157 QUALITY OF MECHANICAL OBSERVATIONS ON PARTICULATE MEDIA

Jacobsen, H. Moust, University of Aalborg, Denmark

A TRUE TRIAXIAL APPARATUS

Introduction

At Aalborg University a true triaxial apparatus has been developed. The basic principle was first used at Cambridge University, but the apparatus has been radically redesigned and reconstructed, and can now be used for undisturbed samples of rather stiff, Danish moraine clays.

The best known laboratory equipment for testing and deformation properties of soil is the traditional "triaxial apparatus". But since in this type the second principal stress always has to equal at least one of the two other principal stresses, the name "triaxial" is misleading. For historical reasons it is difficult to change the name and instead the new equipment is called "the true triaxial apparatus".

The traditional "triaxial apparatus" acts axisymmetrically and the results have to be modified according to experience or empirical rules.

Using the "true triaxial apparatus" it is possible to apply normal stresses to the surface of a sample, which is initially a cube. (Fig. 1). The normal stresses can vary independently and large deformations of the sample can take place. Hence test results can be used directly in practice because it is possible to obtain any desired strain condition. Or the results can be used to built up realistic stress-strain relationships, which can be used in finite element programs or other computer programs.

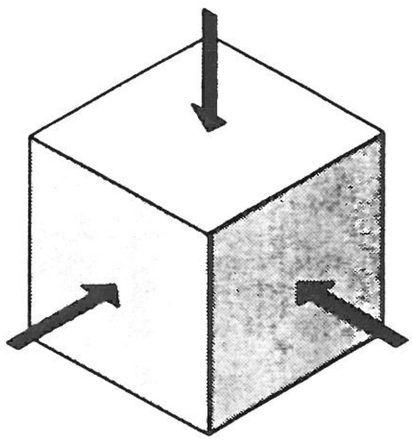


Fig. 1. Cubical sample.

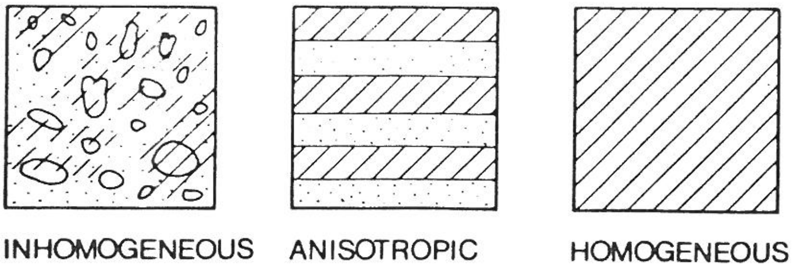


Fig. 2. Some soil types.

The true triaxial apparatus is especially convenient for studies on the anisotropy, a very important, but often neglected characteristic of soil. Fig. 2 shows the structure of different soils. The first specimen is a moraine clay. It is obviously inhomogeneous, but may from a statistical point of view be isotropic. The second specimen with many thin layers is anisotropic and only in few cases does a homogeneous and isotropic soil structure occur. Also the field location of the sample plays an important role. Fig. 3 shows how a soil can be prestressed monoaxially or by large shear stresses in natural slopes. Combined with the fact that the soil is non-elastic a soil element will always be anisotropic.

Therefore the true triaxial apparatus becomes indispensable for a realistic assessment of strength and deformation properties.

Discussion of basic principles

The limitation of the traditional triaxial apparatus has lead to construction of many testing machines, which should be able to apply true triaxial conditions to a soil sample. The sample can be surrounded by flexible faces (rubber bags or membranes) or rigid platens or any combination of these. And many efforts have been spent to limit the discontinuity in stresses and strains to the edges of the sample. Only two principles should be discussed here in order to show the basic problems in true triaxial testing.

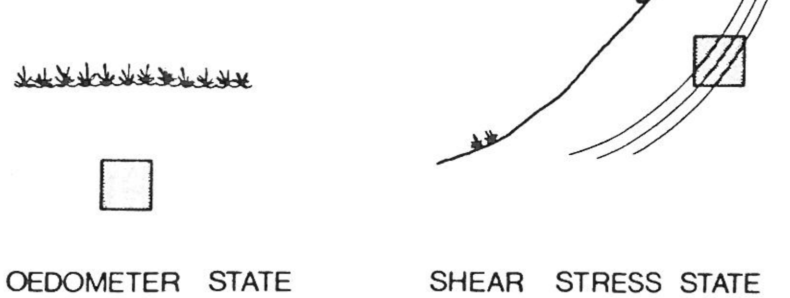


Fig. 3. Natural conditions.

Principle a. Stress control
The sample can be surrounded by rubber bags as shown on fig. 4. The stresses acting on the surface are homogeneously distributed. The test is stress-controlled. During the test the surfaces will not remain plane and the stresses inside the sample will be out of control. Even failure may occur in some part of the sample. The average values of measured strains do certainly not reflect what happens in the sample.

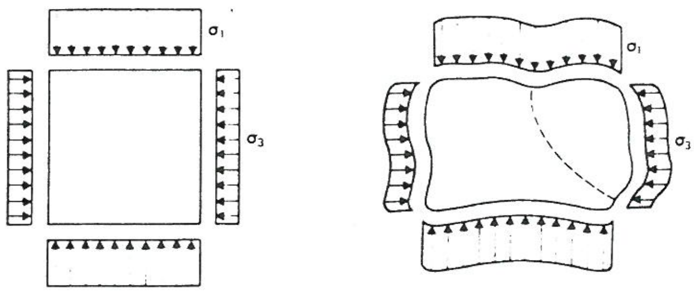


Fig. 4. Controlled stress.

Principle b. Strain control
The sample can also be surrounded by rigid platens, which keep the orientation during the test and force the sample, which is initially a cube, to deform into a right-angled prism. This principle has been used in the Cambridge type and in the Aalborg type and in some earlier types, where the difficulty with altering gaps between the platens has not been overcomed.

The test is strain controlled. In an initially homogeneous sample both the strain and the stress distribution can be considered homogeneous. It means, that the average values of stresses and strains measured outside the sample are representative for every part inside the sample.

Strain controlled tests on moraine clay
Even in a heterogeneous sample of moraine clay the strain control ensures that the differences in normal stresses along a surface do not increase considerably during a test. The average values of measured stresses correspond quite well to the applied strains. It means that this type of testing equipment is suitable for study of stress-strain relationships.

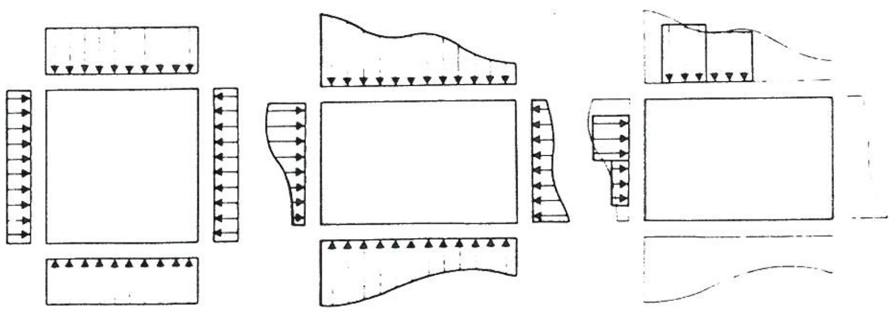


Fig. 5. Controlled strain.

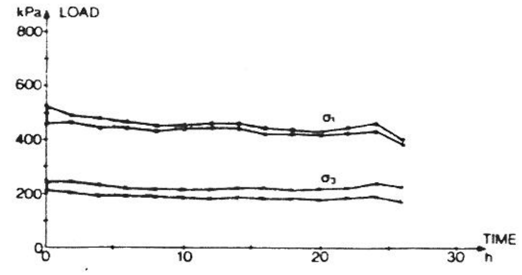


Fig. 6. Stress distribution. Moraine clay.

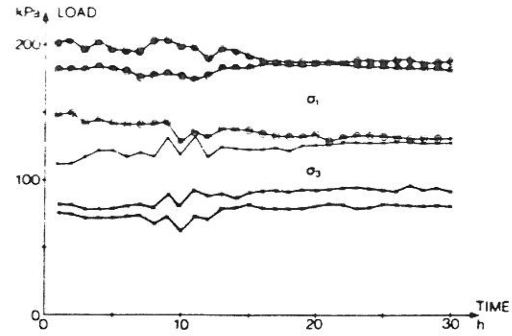


Fig. 7. Stress distribution. Moraine clay.

The normal stresses are measured by means of four load cells per direction. Such cells do of course not give the same result, because the sample is inhomogeneous. Fig. 6 shows the variation in applied normal stresses as two dotted bands. Sometimes the variation can be much bigger as shown in fig. 7, where two of the load cells show considerable deviations caused by inhomogeneities.

The true triaxial apparatus (Aalborg type)

The design based on principle b is shown on fig. 8. The deformation of the cubic sample takes place when the rigid platens slide relatively to each other or push each other. Large movements can take place without gaps being opened between the platens. The gaps are constantly 0.25 mm in thickness and filled with a greased rubber membrane, which prevents attrition of the platen surfaces during sliding. One corner of each platen does not move relatively to the sample and here the drainage system is placed. Fig. 9 shows one of the pressure heads (or platens) with four load cells and the filter disc.

The surface of the pressure head must be very smooth and is therefore polished, greased with silicone and covered with a thin rubber membrane. Experience from the normal triaxial apparatus shows that such a surface can be considered smooth.

In practice the sample is encapsulated by a rubber membrane and placed directly in contact with the greased surfaces of the pressure heads.

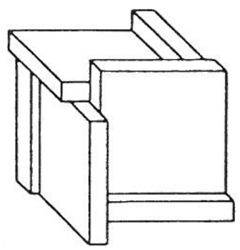


Fig. 8. Sample surrounded by platens.

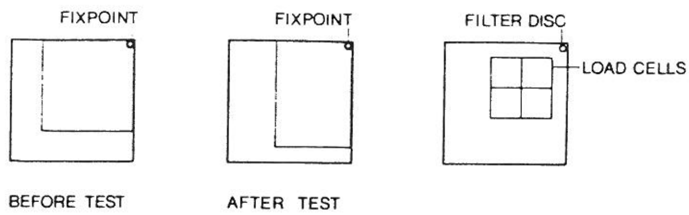


Fig. 9. Movement of sample surface along the pressure head.

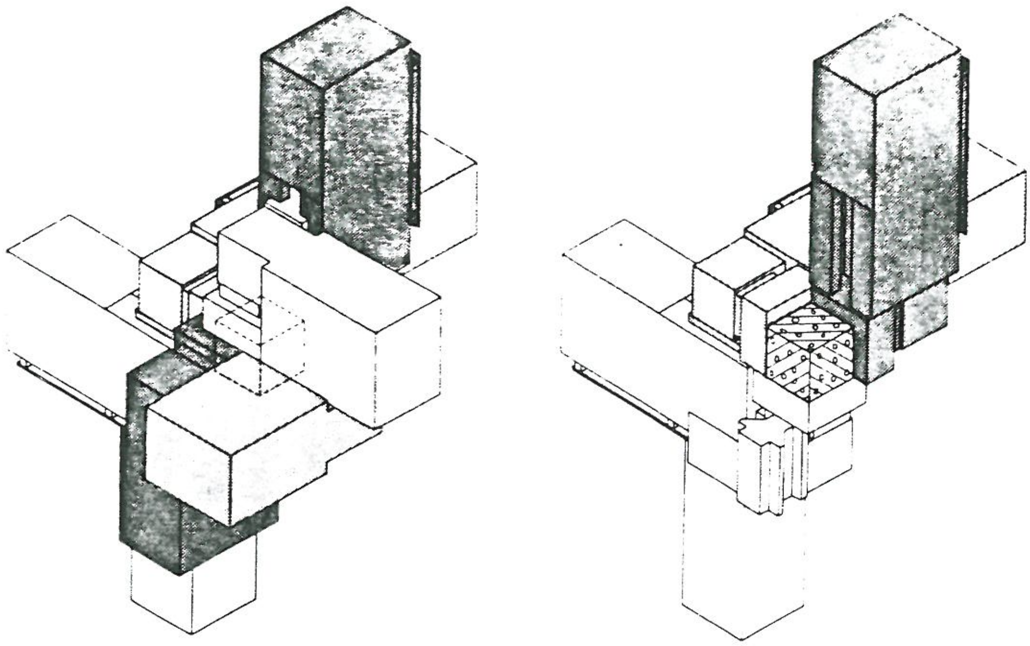


Fig. 10. The true triaxial apparatus.

A load cell consists of a bottom plate and a sensor head (2 x 2 cm square platen) carried by four cylindrical legs with very thin walls (0.08 mm). The sensor heads are flush with the surface of the pressure head and there is a gap of 0.05 mm to 0.1 mm between the sensor heads and the surface.

All the twelve load cells are able to measure normal loads with accuracy. The strain gauges are placed in the middle of the legs, where side movements of the sensor heads do not influence the moment in the leg. Therefore the measurements of normal loads are not influenced by shear forces along the surface.

Three of the load cells are able to measure normal loads by two independent systems, one of which can be used for control purpose.

Three other load cells have additional strain gauges placed at both ends of the legs where the shear force moment is maximum. These measure shear loads in two directions, are very sensitive and check the smoothness of the pressure head.

The apparatus is shown on fig. 10, to the left in a situation just before testing. The apparatus consists of six blocks, which form a three-dimensional frame surrounding the pressure heads. In the middle is the right-angled cavity in which the sample is situated. The length of a side can vary from 5 to 9 cm. The forces from the screw spindles cause considerable moments in the frame which has to be very stiff to prevent distorsion of the pressure heads.

Installation of a sample into the apparatus is rather easy. First three of the blocks are dismounted as shown on fig. 10 to the right. The sample is then placed in the corner and the filtersystem connected simultaneously by means of conical lugs. Then follows successively remounting of the three blocks and connection of the filtersystem.

A block consists of a wedge-shaped sliding mechanism, connections to the two neighbouring blocks and a pressure head. The three blocks, which are permanently mounted to the socket, contain also electrical motors and screw spindles, which operate the deformations of the sample.

The deformation of the sample is measured by transducers mounted on a special frame connected to the socket and bottom plate (not shown).

The testing operation is controlled by an electrical device. It is possible to make tests with constant rate of strain, even zero, constant rate of load or constant load (measured in one point per direction) or tests with constant volume, or any realistic combination from these. The only limitation is that the principal directions remain fixed. So this apparatus replaces oedometers and traditional triaxial apparatuses and opens up for a wide range of new test types.

A datalogging system is able to record all required data at any predetermined time.

Control tests

The mode of operation has been validated by many calibration tests and two test series ending with an almost perfect copy of an oedometer test and an undrained test, which shows some smaller problems. The calibration tests show that the load cells normally are stable for some years, in some cases for more than five years. In that period the calibration curve is a straight line and the standard deviation is very small. Afterwards the standard deviation increases and the calibration factor changes as the strain gauge is destroyed. Therefore the load cells have to be controlled very often, normally before and after each test.

One problem has not yet been considered. That is the error coming from the elasticity of the load cells, relative to the rigidity of the rest of the pressure head. If it is found to be a heavy problem, the solution is to make this part of the pressure head as flexible as the load cells.

The first series consists of oedometer test copies. The vertical load was applied stepwise and horizontal movements prevented. The most serious and time-consuming problem was to keep the vertical load constant during a longer period of time. Fig. 11 and 12 show the results from the two last tests. The stresses are total pressures, each of them a mean value of four recordings. It is noticed, that it was possible to obtain a variation in vertical load σ_1 within a range of few per cent. σ_2 and σ_3 nearly equal, corresponding to stresses in an isotropic soil.

If the load was applied instantaneously the increases of the total pressures should be identical. During the consolidation period σ_2 and σ_3 should decrease and at the end of the process the earth pressure at rest σ_2'/σ_1' or σ_3'/σ_1' could be estimated. Fig. 11 shows that the test results are in accordance with the theory except for the first few minutes, while the load rises.

A normal time curve is shown on fig. 12. The variation in σ_1 seems to cause deformations, which are delayed more than one hour.

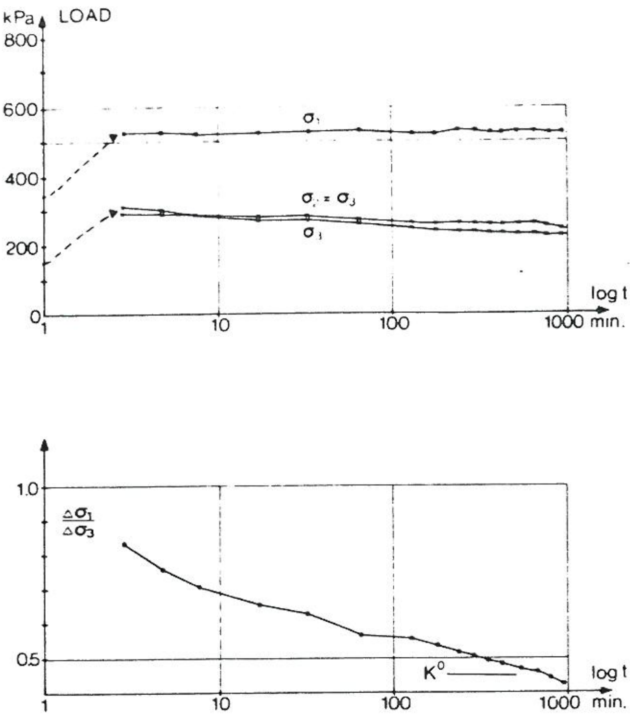


Fig. 11. Development of horizontal, total stresses during consolidation.

The earth pressure at rest measured in different tests is plotted against the vertical pressure on fig. 13. It shows that the results are consistent, but the curve is not representative for a preconsolidated moraine clay, because the stress history has not been reconstructed. It shows the development of K^0 during the virgin loading in the laboratory. When the preconsolidation pressure is exceeded, K^0 becomes constant.

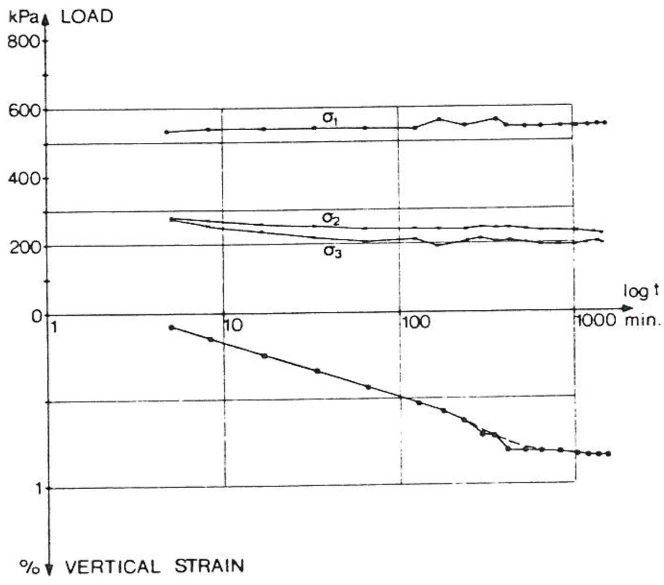


Fig. 12. Oedometer test with time curve.

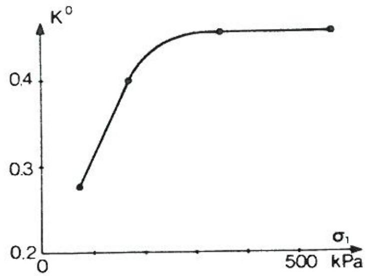
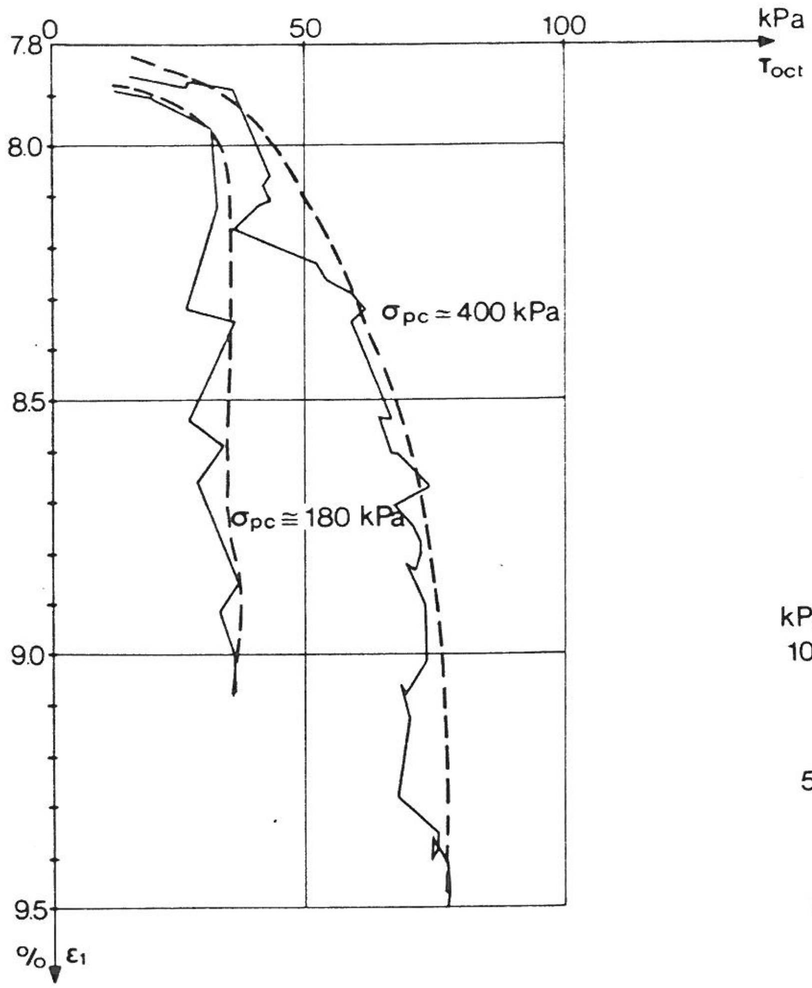


Fig. 13. Earth pressure at rest.



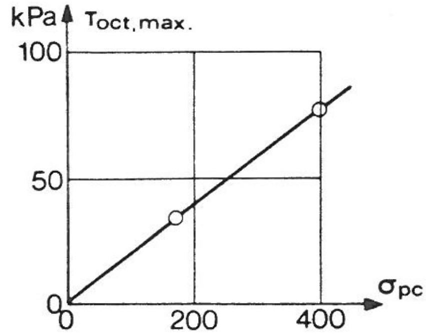


Fig. 14. Undrained, plane strain test.

The second test series consists of undrained, plane strain tests. The results from the two last tests are shown on fig. 14. A test starts with an anisotropic consolidation with many steps. The effective, vertical pressure just before the undrained process is called σ_{pc}. In these two tests the natural preconsolidation pressure has been exceeded. During the undrained part of the test the sample is compressed vertically with constant strain rate. The volume has to be constant and small variations in it control the movements in one of the horizontal directions. It is difficult to control this process and many unloadings and reloadings take place instead of a continuously increase in octahedral shear stress τ_{oct}.

It is possible to determine the undrained shear strength by using the maximum values of τ_{oct}. The two tests show that $\tau_{oct,max}$ is proportional to the preconsolidation pressure σ_{pc}, which is in perfect agreement with the theory for normally consolidated clays. Additionally, it is also possible to make a rough estimate of a performance curve.

Conclusion

A true triaxial apparatus has been developed, which can apply three different normal stresses to the surface of an initially cubical soil sample, by means of rigid and smooth pressure heads. The test operation is strain controlled in order to avoid increasing irregularities during testing.

The performance of the apparatus has been checked by producing test results, which are wellknown from other laboratory equipments such as oedometers and traditional triaxial apparatuses. The apparatus should now be ready for extensive test series.

However, the apparatus seems to be too complicated and too expensive for practical purposes and it will probably be used primarily in the theoretical field to investigate parameters for anisotropic soils in drained and undrained states.

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